SEISMIC HAZARD ZONE REPORT 108

SEISMIC HAZARD ZONE REPORT FOR THE CASTLE ROCK RIDGE 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

2005

DEPARTMENT OF CONSERVATION
California Geological Survey

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CALIFORNIA GEOLOGICAL SURVEY
JOHN PARRISH, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Preliminary Seismic Hazard Zone Map for the Castle Rock Ridge 7.5-Minute Quadrangle released by the California Geological Survey (CGS) on February 11, 2005. Pursuant to the Seismic Hazard Mapping Act of 1990, the map delineates areas that require geotechnical investigations that specifically address liquefaction or earthquake-induced landslides as part of the local agency building permit process. These areas are referred to as Zones of Required Investigation. The preliminary map should become official following the prescribed 90-day public review period and a subsequent 90-day revision period.

The Castle Rock Ridge Quadrangle encompasses about 60-square miles of mainly rugged mountainous terrain in the Santa Cruz Mountains. The quadrangle encompasses land partly within and to the southwest of the city of Saratoga and the community of Monte Sereno, situated about 13 miles south of the San Francisco Bay. At the present time, seismic hazard zonation in the study area is limited to Santa Clara County, which constitutes about 33 percent of the quadrangle. High-density development is generally restricted to lower elevations in the northeastern corner of the quadrangle.

The Seismic Hazard Zone Map was prepared using geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information evaluated includes topography, terrain data, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based on probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

About 65 percent of the 20-square-mile area subject to evaluation in the Castle Rock Ridge Quadrangle is delineated as Zones of Required Investigation for earthquake-induced landslides. The large percentage so delineated is mainly a result of the widespread occurrence of steep slopes and low rock strengths combined with the high ground accelerations expected for this region. On the other hand, less than 1 percent of the area is delineated as Zones of Required Investigation for liquefaction. The liquefaction zones are restricted to a few channels and adjacent floodplains of creeks draining the Santa Cruz Mountains, most notably Saratoga, Lyndon, and San Tomas Aquinas creeks.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm.

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

The Act directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria, which were published in 1992 as CGS Special Publication 118, were revised in 2004. They provide detailed standards for mapping regional liquefaction and landslide hazards. The Act also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water level data in desert regions of the state were adopted by the SMGB. These modifications are reflected in the revised CGS Special Publication 118, which is available on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Castle Rock Ridge 7.5-Minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones of Required Investigation in the Castle Rock Ridge 7.5-Minute Quadrangle, Santa Clara County, California

By
Jacqueline D.J. Bott

California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Santa Clara County portion of the Castle Rock Ridge 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking) complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm.

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta and 1906 San Francisco earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 50 feet of the ground surface. These geological and ground-water conditions are widespread in the San Francisco Bay Area, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard, especially in areas marginal to the San Francisco Bay.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial deposits and artificial fill

- Shallow ground-water maps were constructed

- Geotechnical data were collected and analyzed to evaluate the liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone of required investigation map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2004).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Castle Rock Ridge Quadrangle consist mainly of alluviated valleys, floodplains, and canyon bottoms. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone of required investigation maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, these maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Castle Rock Ridge 7.5-minute Quadrangle map covers approximately 62 square miles in Santa Clara and Santa Cruz counties. The northeastern third of the map area lies in Santa Clara County and includes part of the city of Saratoga, the community of Monte Sereno and other unincorporated parts of Santa Clara County. This report addresses earthquake-induced liquefaction hazards only for those parts of the map that lie within Santa Clara County.

Most of the map area within Santa Clara County is occupied by steeply sloping terrain of two northwest-trending ridges of the Santa Cruz Moutains, El Sereno and Castle Rock Ridge. Two unnamed streams flow along the northeast-trending San Andreas Rift valley, which is located between the two ridges. One stream flows northward into Saratoga Creek near the northern edge of the map, and the other southeastward along Lyndon Canyon and into Lexington Reservoir, which is located within the adjacent Los Gatos quadrangle to the east. Numerous smaller intermittent streams flow northeastward from Castle Rock Ridge into these two streams. A small area at the northeastern tip of the map, which includes part of the City of Saratoga, is occupied by gently sloping terrain. Several small streams, the largest of which is San Tomas Aquinas Creek, flow northeastward out of the hills of El Sereno, and eventually into San Francisco Bay. Elevations in the map area vary from just under 500 ft in the gently sloping terrain in the northeastern corner, to 3231 ft at the top of Mount Bielawski, along Castle Rock Ridge on the boundary of Santa Cruz and Santa Clara counties. Elevations reach 2249 ft at the top of El Sereno and then drop to 1800 ft or less within the San Andreas Rift valley.

The gently sloping terrain and some hilly terrain flanking El Sereno in the northeastern part of the map have been developed for residential uses. Some moderately sloping areas along Black Road, Dyer Canyon and Bear Creek Road, which are located in the unincorporated part of Santa Clara County in the central eastern portion of the map, also have been developed for residential uses. Highway 9 crosses the northeastern tip of the map and Skyline Boulevard follows the crest of Castle Rock Ridge close to the Santa Clara-Santa Cruz county boundary. Sanborn Skyline County Park occupies the northern part of the northeast-facing slope of Castle Rock Ridge, extending down to the creek along the San Andreas Rift valley.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the deposits in the Castle Rock Ridge Quadrangle, recently completed maps of the nine-county San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000) and bedrock mapping (Wentworth, unpublished mapping, 2003) were obtained from the USGS in digital form. The map by Wentworth (unpublished mapping, 2003) attempts to reconcile the differences between mapping by McLaughlin and others (2001) for the Los Gatos Quadrangle and mapping of Wentworth and others (1999) and Brabb and others (1998) for the San Jose and Palo Alto 30 x 60-Minute quadrangle maps, respectively. Mapping of Quaternary deposits by Knudsen and others (2000) was updated by Bott (unpublished) in this study. Mapping by Bott (unpublished) was based on 1940 and 1999 aerial photographs, 1991 Digital Orthophoto Quadrangles and limited field reconnaissance. The GIS maps were combined, with some modifications along the bedrock/Quaternary contact. The result was a single 1:24,000-scale geologic map of the Castle Rock Ridge Quadrangle. The distribution of Quaternary deposits on this map (Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the Liquefaction Zones of Required Investigation.

Other geologic maps and reports were reviewed during this investigation, including: Dibblee (unpublished mapping), DWR (1967), Helley and Brabb (1971), Rogers and Armstrong (1972), Rogers and Williams (1974), Cooper-Clark (1975), Sorg and McLaughlin (1975), William Cotton and Associates (1977), Pulver (1979), Manson and others (1991), Helley and others (1994), Brabb and others (1998), Wentworth and others (1999), DOC (2000), McLaughlin and others (2001), and Reymers and Hemmeter (2002). Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

In the Castle Rock Ridge Quadrangle, seven Quaternary map units and the Plio-Pleistocene Santa Clara Formation (QTsc) were mapped (Table 1.1). The Quaternary geologic mapping methods described by Knudsen and others (2000) consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. The authors estimate the ages of deposits using: landform shape, relative geomorphic position, cross cutting relationships, superposition, depth and degree of surface dissection, and relative degree of soil profile development. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000), Bott (unpublished) and the CGS GIS database, with that of several previous studies performed in northern California.

Less than 10% of the Santa Clara County portion of the Castle Rock Ridge Quadrangle is covered by Late Quaternary deposits. These areas include the gently sloping terrain in the northeastern corner of the quadrangle and areas along the two streams that flow along the San Andreas rift zone (Plate 1.1).

The Holocene alluvial fan and fluvial deposits have been divided into the following units: Qhc, Qht, and Qha. Active stream channel deposits (Qhc) are mapped along the bed of Saratoga Creek and all its tributaries in the north central portion of the map. Undifferentiated Holocene alluvium (Qha) has been mapped along San Tomas Aquinas Creek, which flows through the City of Saratoga in the northeastern corner of the map. Along the flanks of this stream channel, two sets of Holocene stream terrace deposits have been mapped (Qht1 and Qht2, the former of which is inset into the latter). Late Pleistocene to Holocene fluvial deposits have been mapped along the creek that flows along Lyndon Canyon and into Lexington Reservoir, in the east-central portion of the map. Undifferentiated alluvium (Qa) is mapped along the stream channel, and some stream terrace deposits (Qt) are mapped where the first tributary enters the main channel. Some Late Pleistocene to Holocene stream terrace deposits (Qt) are mapped at the junction of several tributary streams to Saratoga Creek in the north-central portion of the map. Late Pleistocene alluvial fan deposits (Qpf) cover much of the gently sloping terrain in the northeast corner of the map and a large, gently sloping area along the main tributary to Saratoga Creek that flows northwards along the San Andreas Rift Zone.

Bedrock exposed in the Castle Rock Ridge Quadrangle is characterized by two basement assemblages that are separated by the San Andreas Fault, which extends through the northeastern portion of the quadrangle (Brabb and others, 1998). Southwest of the San Andreas Fault is the Salinian Complex, a basement assemblage of granitic and gabbroic plutonic rocks. Northeast of the San Andreas Fault is a composite Mesozoic basement assemblage consisting of the Franciscan Complex, the Coast Range Ophiolite, and the Great Valley Sequence. Brabb and others (1998) further subdivide bedrock sequences in the area into individual fault-bounded structural blocks based on differing stratigraphic sequences and geologic history of the basement assemblages and overlying Tertiary rocks. See the earthquake-induced landslide part (Section 2) of this report for additional description of bedrock geology.

UNIT	Knudsen and others (2000); Bott (unpublished)	Helley and others (1994)	Helley and others (1979)	Brabb and others (1998)	CGS GIS database
Artificial fill	af			af	af
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhsc	Qhc
Holocene stream terrace deposits	Qht	Qhfp			Qht
Holocene alluvium, undifferentiated	Qha				Qha
Late Pleistocene to Holocene stream terrace deposits	Qt				Qt
Late Pleistocene to Holocene alluvium, undifferentiated	Qa				Qa
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpa	Qpaf	Qpf
bedrock	br	br			br

Table 1.1 Correlation Chart of Quaternary Stratigraphic Nomenclatures Used in Previous Studies. For this study, CGS has adopted the nomenclature of Knudsen and others (2000).

Structural Geology

The Castle Rock Ridge Quadrangle encompasses a 6.5-mile segment of the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The northwest trending San Andreas Fault crosses the northeastern corner of the Castle Rock Ridge Quadrangle, and the similarly oriented Calaveras fault is approximately 14 miles northeast of the quadrangle's northeastern corner. Historical ground surface-rupturing earthquakes have occurred on these two faults (Lawson, 1908; Keefer and others, 1980). The Berrocal thrust fault zone is mapped near the base of the foothills of the Santa Cruz Mountains in the northeast corner of the quadrangle by Sorg and McLaughlin (1978) and by McLaughlin and others (1991).

ENGINEERING GEOLOGY

Soils that are susceptible to liquefaction are mainly late Quaternary alluvial deposits and artificial fill. Deposits that contain saturated loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits. For this investigation, however, no borehole logs were available for the area where Quaternary deposits are mapped. Therefore, data from neighboring quadrangles (Cupertino and Los Gatos) were used to characterize the deposits within the Castle Rock Ridge Quadrangle.

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 2004). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Geotechnical and environmental borehole logs from neighboring quadrangles provided information on lithologic and engineering characteristics of Quaternary deposits within this quadrangle. Geotechnical characteristics of the mapped units are generalized in liquefaction evaluation reports for Cupertino and Los Gatos quadrangles (see Tables 1.2 in the evaluation reports for those quadrangles).

GROUND WATER

Saturation reduces the effective normal stress of near-surface sediment, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS compiles and interprets ground-water data to identify areas characterized by, or anticipated to have in the future, near-surface saturated soils. For purposes of seismic hazard zonation, "near-surface" means at a depth less than 50 feet.

Natural hydrologic processes and human activities can cause ground-water levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils during future earthquakes. One method of addressing time-variable depth to saturated soils is to establish an anticipated high ground-water level based on historical ground-water data. In areas where ground water is either currently near-surface or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps that depict these levels.

CGS delineates present or anticipated near-surface saturated soils caused by locally perched water and seepage from surface-water bodies.

Ground-water conditions were investigated in the Castle Rock Ridge Quadrangle to evaluate the depth to saturated materials. Based on data from adjacent quadrangles and depths of incision to creeks in this quadrangle, it is assumed that ground water lies within about 20 ft of the ground surface (Plate 1.2).

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2004).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.2.

Modern stream channel deposits (Qhc) where water levels are within 30 feet of the ground surface have been given susceptibility assignments of high (H) to very high (VH) (Table 1.2). Holocene terrace deposits (Qht) and undifferentiated Holocene alluvium (Qha) have lower susceptibility assignments of moderate (M) where water levels are within 30 feet of the ground surface. All late Pleistocene to Holocene deposits (Qa and Qt) within 30 feet of the ground surface have moderate (M) to low (L) susceptibility assignments depending on depth to ground water. Late Pleistocene alluvial fan deposits (Qpf) have low (L) susceptibility to liquefaction, being coarser and more indurated than younger deposits. Uncompacted artificial fill and modern stream terrace deposits have moderate (M) susceptibility assignments where they are saturated between 30 and 40 feet. All other units have low (L) to (VL) susceptibility assignments below 30 feet of the ground surface. These susceptibilities are based on geotechnical characteristics as assessed in neighboring quadrangles (Cupertino and Los Gatos), as no geotechnical data was available for these units within the Castle Rock Ridge Quadrangle.

Table 1.2 Liquefaction Susceptibility for Quaternary Map Units within the Castle Rock Ridge 7.5 Minute Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground water depth within that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

Geologic Unit (1)	Description	Number of Historical Occurrences	Composition by soil type (Unified Soil Classification System Symbols)	Depth to ground water (ft) (2) and liquefaction susceptibility category assigned to geologic unit			
				<10	10 to 30	30 to 40	>40
af	Artificial fill (3)	0	n/a(4)	VH - L	H - L	M - L	VL
Qhc	Modern stream channel deposits	0	n/a	VH	H	M	VL
Qht	Holocene stream terrace deposits	0	n/a	M	M	L	VL
Qha	Holocene alluvium, undifferentiated	0	n/a	M	M	L	VL
Qt	Late Pleistocene to Holocene stream terrace deposits	0	n/a	M	L	L	VL
Qa	Late Pleistocene to Holocene alluvium, undifferentiated	0	n/a	M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	0	n/a	L	L	VL	VL
QTsc	Santa Clara Formation	0	n/a	VL	VL	VL	VL

Notes:

(1) Susceptibility assignments are specific to the materials within the Castle Rock Ridge 7.5-Minute Quadrangle.

(2) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.

(3) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.

(4) n/a = not applicable

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2004). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Castle Rock Ridge Quadrangle, PGAs of 0.57 to 0.82g, resulting from an earthquake of magnitude of 7.9 are estimated for alluvial conditions. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996). See the ground motion section (3) of this report for further details.

LIQUEFACTION ZONES OF REQUIRED INVESTIGATION

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2004). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:

    a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the anticipated depth to saturated soil is less than 40 feet; or

    b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or

    c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of these criteria allows compilation of liquefaction zones of required investigation, which are useful for preliminary evaluations, general land-use planning and delineation of special studies zones (Youd, 1991).

Areas of Past Liquefaction

In the Castle Rock Ridge Quadrangle, no areas of documented historical liquefaction are known.

Artificial Fills

In the Castle Rock Ridge Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for a small dam constructed on a tributary of Saratoga Creek. Since this fill body is likely to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. The fill body is therefore not included in the zone of required investigation.

Areas with Insufficient Existing Geotechnical Data

Geotechnical data was not available for the area in the Castle Rock Ridge Quadrangle within Santa Clara County. The liquefaction zone of required investigation includes areas mapped as modern stream channels, Holocene undifferentiated alluvium and stream terraces, and late Quaternary to Holocene undifferentiated alluvium. These deposits are near active stream channels, where ground water is at or close to the surface and so are likely to be saturated. Therefore, these areas have been included in the zone of required investigation based on the critieria 4b) as described above. Late Pleistocene to Holocene stream terrace deposits are not included in the zone of required investigation, being 40 ft or more above the active stream channels.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Castle Rock Ridge 7.5-Minute Quadrangle, Santa Clara County, California

By
Mark O. Wiegers and Jacqueline D.J. Bott

California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf.

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Castle Rock Ridge 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Castle Rock Ridge Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2004).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Castle Rock Ridge Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Castle Rock Ridge Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Castle Rock Ridge 7.5-minute Quadrangle map covers, approximately 62 square miles in Santa Clara and Santa Cruz counties. The northeastern third of the map area lies in Santa Clara County and includes parts of the city of Saratoga, the community of Monte Sereno, and other unincorporated parts of Santa Clara County. This report addresses earthquake-induced landslide zones for those parts of the map that lie within Santa Clara County only.

Most of the map area within Santa Clara County is occupied by steeply sloping terrain of two northwest-southeast trending ridges of the Santa Cruz Moutains, El Sereno and Castle Rock Ridge. Two streams flow along the valley formed by the San Andreas Rift Zone, which is located between El Sereno and Castle Rock Ridge. One stream flows northward into Saratoga Creek near the northern edge of the map and the other southeastward along Lyndon Canyon and into Lexington Reservoir, located within the adjacent Los Gatos Quadrangle to the east. Numerous smaller creeks that flow northeastward down from Castle Rock Ridge feed these two streams. A small area at the northeastern tip of the map, which includes part of the City of Saratoga, is occupied by gently sloping terrain. Several small streams, the largest of which is San Tomas Aquinas Creek, flow northeastwards out of the hills of El Sereno, and eventually flow into San Francisco Bay. Elevations in the map area vary from just under 500 ft in the more gently sloping terrain in the northeastern corner, to 3231 ft at the top of Mount Bielawski, along Castle Rock Ridge on the boundary of Santa Cruz and Santa Clara counties. Elevations reach 2249 ft at the top of El Sereno and then drop to 1800 ft or less within the northwest-southeast trending San Andreas Rift valley.

The gently sloping terrain and some hilly terrain flanking El Sereno in the northeastern part of the map have been developed for residential uses. Some moderately sloping areas along Black Road, Dyer Canyon and Bear Creek Road, which are located in Santa Clara County in the central eastern portion of the map, also have been developed for residential uses. Highway 9 crosses the northeastern tip of the map and Skyline Boulevard follows the crest of Castle Rock Ridge that separates Santa Clara and Santa Cruz counties. Sanborn Skyline County Park occupies most of the northeast-facing slope of Castle Rock Ridge, that extends down to the creek along the San Andreas Rift valley.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth’s surface in the form of a digital topographic map. Within the Castle Rock Ridge Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1953 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was an unpublished map by Wentworth (2003) obtained from the U.S. Geological Survey. Wentworth (2003) attempts to reconcile the differences between the Palo Alto 100,000-scale geologic map of Brabb and others (1998), and the San Jose 100,000-scale geologic map of Wentworth and others (1999). Wentworth's 2003 mapping of the Franciscan rocks reflects a more current understanding of tectonics of the area and incorporates detailed geologic mapping by Sorg and McLaughlin (1979) along the Sargent-Berrocal fault zone. Quaternary surficial deposits are not extensive in the Castle Rock Ridge Quadrangle and the existing bedrock geologic maps do not portray them accurately. The author of Section 1 of this report (J. Bott) prepared a Quaternary geologic map for this study that matches the mapping by Knudsen and others (2001) in adjacent quadrangles. Surficial geology is discussed in detail in Section 1 of this report.

CGS geologists modified the digitized geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate GIS layers for the hazard analysis. Contacts between bedrock and Quaternary surficial units were revised to better conform to the topographic contours of the USGS 7.5-minute quadrangle. Air-photo interpretation and limited field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units and to review lithology of geologic units and geologic structure.

The geology of the Castle Rock Ridge Quadrangle is characterized by two basement assemblages that are separated by the San Andreas Fault, which extends through the northeastern corner of the quadrangle. Northeast of the San Andreas Fault is a composite Mesozoic basement assemblage consisting of the Franciscan Complex, Coast Range Ophiolite, and the Great Valley Sequence. Southwest of the San Andreas Fault is the Salinian Terrane of the Santa Cruz block, a basement assemblage of granitic and metamorphic crystalline rocks.

The bedrock sequences have been further subdivided into fault-bounded structural blocks based on differing stratigraphic sequences and geologic histories, and overlying Tertiary rocks (McLaughlin and others, 2001). McLaughlin and others (2001) and Brabb and others (1998) divide the regions differently and use differing names for their blocks or assemblages. In the Castle Rock Ridge Quadrangle McLaughlin and others (2001) subdivide the Santa Cruz block south of the San Andreas Fault into two smaller blocks, the La Honda and Ben Lomond blocks, which are separated by the Zayante fault. Brabb and others (1998) subdivide this region into three fault-bounded blocks, the Mindego Hills, Butano Ridge and Santa Cruz assemblages, which are separated by the Butano and Zayante faults, respectively. Northeast of the San Andreas Fault, McLaughlin and others (2001) define two blocks, the Sierra Azul and New

Almaden blocks whereas Brabb and others (1998) describe only the Woodside Assemblage. The Sierra Azul block of McLaughlin and others (2001) is only exposed within a narrow strip along the San Andreas Fault zone in the Castle Rock Ridge Quadrangle. Rocks exposed within each structural block in the Castle Rock Ridge Quadrangle are described below.

New Almaden and Sierra Azul blocks (Woodside Assemblage)

The New Almaden and Sierra Azul blocks occupy the northeastern corner of the Castle Rock Ridge Quadrangle. The New Almaden block underlies the Sierra Azul block and is separated from it by a system of faults superimposed on the Coast Range Thrust. The New Almaden block has a basement consisting of rocks of the Franciscan Complex tectonically interleaved with rocks of the Coast Range Ophiolite of the Sierra Azul block. The basement is overlain by Miocene marine strata and Pliocene and Pleistocene sediment. Miocene and later strata have been deformed by reverse faulting along the Sargent, Berrocal and Shannon fault zones (McLaughlin and others, 2001). The Sierra Azul block is bounded by the San Andreas Fault on the southwest and is juxtaposed against the La Honda block of McLaughlin and others (2001) or what Brabb and others (1998) call the Mindego Hills Assemblage (see below).

Wentworth (2003) has adopted some geologic units from mapping by Sorg and McLaughlin (1979) and McLaughlin and others (2001) and some from mapping by Brabb and others (1998) for this block.

Several distinct Franciscan Complex rocks of Jurassic and Cretaceous age are mapped in the Castle Rock Ridge Quadrangle. Sandstone (fss) consists of fine to coarse-grained graywacke with interbedded siltstone and shale. A separate unit of Franciscan Sandstone of the Marin Headlands Terrane (fms) is mapped along the west side of the map area and extends onto the adjacent Los Gatos Quadrangle (McLaughlin and others, 2001). Greenstone (fg) consists of basaltic flows, pillow lavas, breccias, tuffs and minor related intrusive rocks. Chert (fc) consists of thin to thick layers and is commonly rhythmically interbedded with thin shale layers. Melange (fm) consists of sandstone, siltstone and shale that has been extensively sheared but locally contains resistant blocks of relatively unsheared rock.

Two rocks of the Coast Range Ophiolite (Sierra Azul block) are mapped in the Castle Rock Ridge Quadrangle. Serpentinite (Jos) is exposed in small fault-bounded bodies enclosed in Franciscan rocks. It is slightly to extensively sheared and contains some altered ultramafic rock. Diabase and gabbro (db) of Jurassic (?) age are mapped in a fault-bounded belt along the northeast side of the San Andreas Fault. Also part of the Sierra Azul block are some unnamed sedimentary rocks (Tu), possibly of Eocene age, mapped in fault bounded blocks along the San Andreas Fault zone.

The Santa Clara Formation (QTsc) of upper Pliocene to lower Pleistocene age consists of non-marine, poorly indurated conglomerate, sandstone, and mudstone in lenticular beds. It is exposed along a belt of low foothills on the margin of the Santa Clara Valley and has been faulted against the Franciscan rocks along the Berrocal fault zone.

Santa Cruz block (Mindego Hills, Butano Ridge and Santa Cruz Assemblages)

The Santa Cruz block occupies the central and southern portion of the Castle Rock Ridge Quadrangle and is separated from the New Almaden and Sierra Azul blocks by the northwest-trending San Andreas Fault. The basement complex of the Santa Cruz block is not exposed in the Castle Rock Ridge Quadrangle. McLaughlin and others (2001) subdivide this block into two subsidiary fault blocks, the La Honda block and the Ben Lomond block, separated by the Zayante Fault. Exposed Tertiary rocks of the La Honda block consist of a thick section of Eocene through Pliocene strata, the total thickness of which is as much as 6 km (McLaughlin and others, 2001). Brabb and others (1998) mapped three distinct assemblages within the Castle Rock Ridge Quadrangle southwest of the San Andreas Fault. These assemblages, from northeast to southwest, are the Mindego Hills, the Butano Ridge and the Santa Cruz assemblages and they are separated by the Butano and Zayante faults, respectively. The following units within the Santa Cruz block are exposed in the Santa Clara County portion of the Castle Rock Ridge Quadrangle.

The Lambert Shale (Tla) of Oligocene to lower Miocene age consists of mudstone, siltstone and claystone (Brabb and others, 1998). It contains some chert in the upper section, and in some places thick sandstone beds and microcrystalline dolomite. The Mindego Basalt (Tmb), mapped within the Vaqueros Sandstone and the San Lorenzo Formation, of Miocene and/or Oligocene age, consists of extrusive and intrusive basaltic volcanic rock. Extrusive rocks include flow breccias, tuffs, pillow lavas and flows. The Vaqueros Sandstone (Tvq) of lower Miocene and Oligocene age consists of fine- to coarse-grained arkosic sandstone interbedded with mudstone and shale. The San Lorenzo Formation (Tsl) is Oligocene and upper and middle Miocene in age and consists of shale, mudstone and siltstone with some local sandstone interbeds (Brabb and others, 1998).

Structural Geology

Rocks within the Castle Rock Ridge Quadrangle have undergone a complex structural history and have been strongly deformed by faulting and folding. Rocks within the different blocks or assemblages described above have each undergone different depositional and deformational histories and have been juxtaposed against one another by a complex system of Tertiary and Quaternary strike-slip and dip-slip faults.

The major fault within the Castle Rock Ridge Quadrangle is the San Andreas Fault, which juxtaposes two very different basement assemblages, Franciscan to the northeast and Salinian to the southwest. The San Andreas Fault is a NW-trending, right-lateral, strike-slip fault with an estimated offset of 35 km in the last 8 million years (Brabb and others, 1998). The San Andreas Fault is comprised of many strands that form a zone, which is up to 1 km wide within the Castle Rock Ridge Quadrangle. Lawson (1908) reported surface rupture and cracking resulting from the 1906 San Francisco earthquake in the vicinity of Lake Ranch Reservoir and farther south along the southwest side of Lyndon Creek. A number of large landslide blocks are present in the Santa Cruz block adjacent to the San Andreas Fault, some of which have been cut by the fault and may well have been seismically induced.

Oligocene to Miocene rocks in the Santa Cruz block within the Castle Rock Ridge Quadrangle have been folded and faulted. Some strata are steeply dipping and in places overturned and a few anticlines and synclines have been mapped by Brabb and others (1998) approximately subparallel to the San Andreas Fault within the Vaqueros and San Lorenzo formations. The Butano and another unnamed fault cut these formations in a similar orientation to the fold axes. The Butano Fault is depicted as a steeply dipping reverse fault by McLaughlin and others (2001) in the adjoining Los Gatos Quadrangle that is subparallel to the Summit Syncline. Brabb and others (1998) surmise that deformation between the Butano Fault and the San Andreas Fault (Mindego Hills Assemblage) was pre-Pliocene in age and that most of the movement along the Butano Fault had occurred by Pliocene or latest Miocene time. Brabb and others (1998) note a northeastward younging trend in the faulting with the San Andreas Fault being the locus of Holocene activity.

Pliocene and Pleistocene Santa Clara Formation (QTsc) deposits have been tilted in the Cupertino Quadrangle just north of the Castle Rock Ridge Quadrangle along the base of the foothills just east of the Berrocal Fault zone.

Landslide Inventory

An inventory of existing landslides in the Castle Rock Ridge Quadrangle was prepared by analysis of stereo-paired aerial photographs, analysis of shaded relief maps of digital elevation data (USGS 10-m DEM), review of previously published landslide maps (Cooper-Clark and Associates, 1975; William Cotton and Associates, 1975; Pulver, 1979; Sorg and McLaughlin, 1979; Manson and others, 1991; DOC, 2000; Wentworth, 2003), and by field reconnaissance. Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were incorporated into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the landslide zoning due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are abundant in the Santa Clara County portion of the Castle Rock Ridge Quadrangle, particularly within the Tertiary strata south of the San Andreas Fault. Landslides in the area range from minor shallow surficial failures like debris slides and flows, to large rotational and translational landslides, some of which are relatively old and deeply eroded. Several large ancient landslide complexes have been mapped in the south-central portion of the Castle Rock Ridge Quadrangle along the northeast-facing slope just south of and within the San Andreas Fault zone (Cooper-Clark and Associates, 1975; Wentworth, 2003; this study). These consist of deep complex translational and rotational slides involving the Vaqueros Sandstone and the San Lorenzo Formation. The San Andreas Fault has cut the toes of some of these slides. Several smaller, recently active slides occur within these complexes. The boundaries of these large landslide complexes are often difficult to delineate because the slides have been extensively modified by erosion and so their mapped extent varies with author. The majority of debris slides are shallow and are mapped in Franciscan rocks northeast of the San Andreas Fault, whereas the majority of deep rockslides are mapped within the Tertiary sedimentary strata southeast of the San Andreas Fault.

The distribution of landslides mapped for this study was compared to the mapping by others for the Castle Rock Ridge Quadrangle (Cooper-Clark and Associates, 1975; William Cotton and Associates, 1975; Pulver, 1979; Sorg and McLaughlin, 1979; Manson and others, 1991; DOC, 2000; Wentworth, 2003). Most of the landslides mapped by Cooper-Clark and Associates (1975) are included in this study, but often the boundaries are mapped differently. Many more landslides have been mapped in this study than were mapped by Cooper-Clark and Associates, and a few landslides mapped by them were not included herein. Pulver (1979) only mapped some landslides identified in this study and some of his landslides were not included. Sorg and McLaughlin (1979) mapped some landslides in the area northeast of the San Andreas Fault on their map of the Sergent-Berrocal Fault Zone and all of these slides that could be observed on aerial photos were included in this study. Detailed landslide mapping of the Congress Springs slide and surrounding area by William Cotton and Associates (1975) was included in this study.

Manson and others (1991) identified about 40 small rock or soil slides and slumps (mostly less than 100 m^3 in size) that were triggered by the 1989 Loma Prieta earthquake within the Santa Clara County portion of the Castle Rock Ridge Quadrangle. The majority of these were within the large landslide complex mapped along the San Andreas Fault zone or along Skyline Boulevard. Manson and others (1991) also mapped several small rock or soil slides in the hills above Saratoga just east of the Congress Springs Landslide. These authors did not delineate the boundaries of these slides, and these features were not included in the landslide inventory due to their small size.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Castle Rock Ridge Quadrangle geologic map were obtained from the counties of Santa Clara and Santa Cruz, the City of Los Gatos and the office of Cotton, Shires and Associates, geotechnical reviewers for the cities of Saratoga and Cupertino (see Appendix A). The locations of rock and soil samples taken for shear testing within the Castle Rock Ridge Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Cupertino, Los Gatos and Laurel quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Castle Rock Ridge Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength groups are summarized in Table 2.1. For each geologic strength group

(Table 2.2) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Three geologic units, the Butano Sandstone (Tbu), the Vaqueros Sandstone (Tvq) and the San Lorenzo Formations (Tsl) were subdivided further as discussed in the next section

Adverse Bedding Conditions

Adverse bedding conditions can be an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, were used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, the area was marked as a potential adverse bedding area. Adverse bedding conditions were not evaluated on gentle slopes of less than 25% because adverse bedding is not likely to contribute to slope instability on gentle slopes.

The Butano Sandstone (Tbu), the Vaqueros Sandstone (Tvq) and the San Lorenzo Formations (Tsl), which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Butano Sandstone (Tbu), the Vaqueros Sandstone (Tvq) and the San Lorenzo Formations (Tsl) are included in Table 2.1.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

CASTLE ROCK RIDGE QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tbu(fbc) (4)	9	36	35/34	625/430	fms	35
	fss (1)	11	34/33				
	Tvq(fbc) (1)	5	38/32				
	db (1)	4	35/36				
GROUP 2	fm (3)	8	30/35	31/30	837/557	fc	31
	fg (3)	10	34/29			Tmb	
	Qp (2)	41	31/31				
	Tsl(fbc) (1)	5	31/31				
GROUP 3	Jos (5)	33	28/24	28/26	750/500	Tu	28
	Qh (2)	18	27/29			af	
	Tvq(abc) (1)	1	29/29				
GROUP 4	QTsc (3)	114	27/25	26/25	939/800	Tla	25
	Tbu(abc) (4)	13	25/24				
	Tsl(abc) (1)	6	23/26				
GROUP 5	Qls(5)	12	12/8	12/8	n/r		12

fbc = Favorable bedding conditions
abc = Adverse bedding conditions
(1) includes tests from Los Gatos Quadrangle
(2) includes tests from Los Gatos and Cupertino Quadrangles
(3) includes tests from Cupertino Quadrangle
(4) includes tests from Laurel Quadrangle
(5) residual shear tests from Nelson , 1992

Table 2.1. Summary of the Shear Strength Statistics for the Castle Rock Ridge Quadrangle.

SHEAR STRENGTH GROUPS FOR THE CASTLE ROCK RIDGE 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Tbu(fbc)	Qp	Qh	QTsc	Qls
Tvq(fbc)	Tsl(fbc)	Tvq(abc)	Tbu(abc)	
fss	fm	Tu	Tsl(abc)	
db	fg	Jos	Tla	
	fc	af		

Table 2.2. Summary of Shear Strength Groups for the Castle Rock Ridge Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Castle Rock Ridge Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996).

The parameters used in the record selection are:

Modal Magnitude:	7.9
Modal Distance:	2.8 – 7.1 km
PGA:	0.77 – 0.97 g

The strong-motion record selected for the slope stability analysis in the Castle Rock Ridge Quadrangle was the Southern California Edison Lucerne record from the 1992 magnitude 7.3 Landers earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.73g. Although the modal distance and magnitude for the Lucerne record do not fall within the range or are not the same as the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to threshold yield accelerations of 0.14, 0.18 and 0.24g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Castle Rock Ridge Quadrangle.

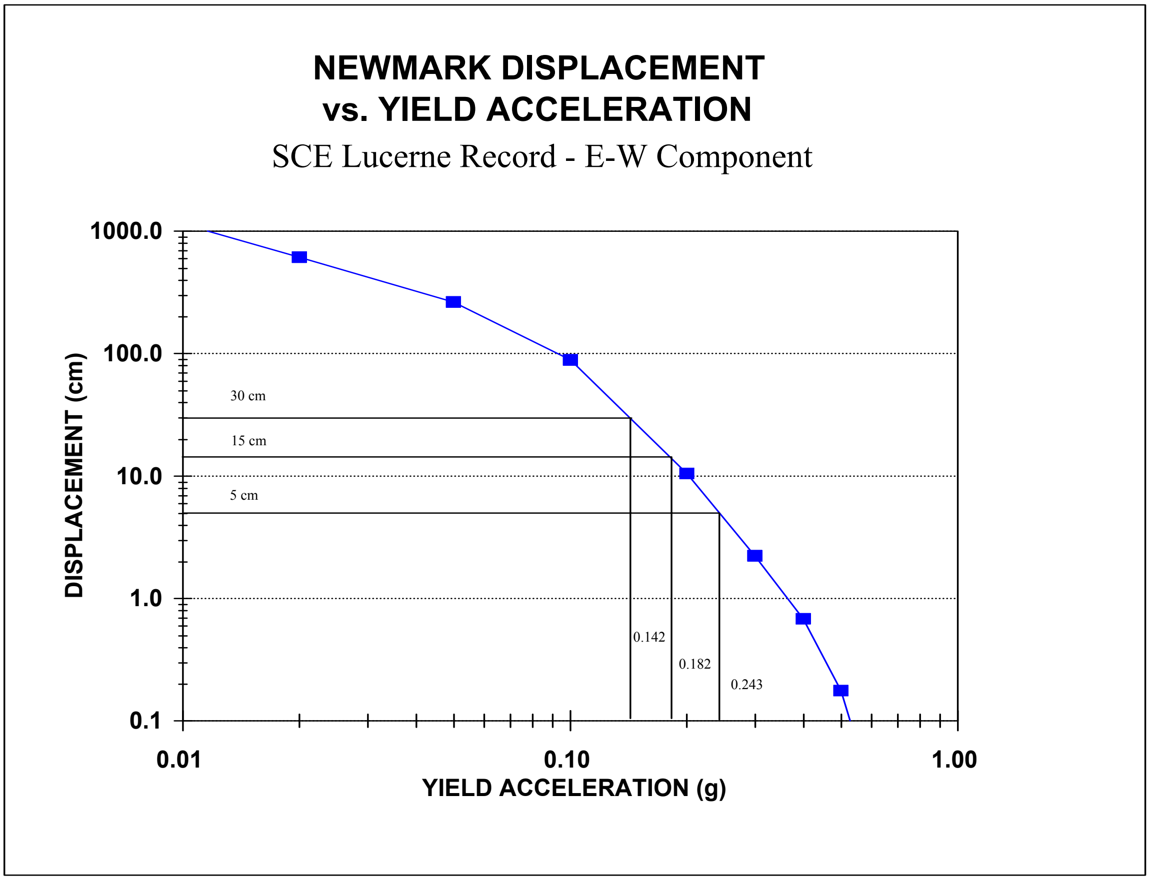

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.

2. If the calculated yield acceleration fell between 0.14g and 0.18g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.

3. If the calculated yield acceleration fell between 0.18g and 0.24g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.

4. If the calculated yield acceleration was greater than 0.24g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

CASTLE ROCK RIDGE QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (% Slope)			
	Very Low	Low	Moderate	High
1 (35)	0 to 44%	44 to 50%	50 to 55%	> 55%
2 (31)	0 to 34%	34 to 42%	42 to 47%	> 47%
3 (28)	0 to 29%	29 to 34%	34 to 38%	> 38%
4 (25)	0 to 23%	23 to 29%	29 to 32%	> 32%
5 (12)	0%	0 to 7%	7 to 12%	> 12%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Castle Rock Ridge Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included in the zone for all slope gradient categories. (Note: The only geologic unit included in Geologic Strength Group 5 is Qls, existing landslides. They have been included or excluded from the landslide zones on the basis of the criteria described in the previous section)

2. Geologic Strength Group 4 is included for all slopes steeper than 23 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 29 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 34 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 44 percent.

This results in approximately 65 percent of the Santa Clara County portion of the Castle Rock Ridge quadrangle lying within the earthquake-induced landslide hazard zone of required investigation.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Jim Baker with the County of Santa Clara, Suzanne Davis and Bud Lortz with the Town of Los Gatos, and Bill Cotton, Bill Cole and Ted Sayre and the staff at Cotton, Shires and Associates, Inc. At CGS, Terilee McGuire, Lee Wallinder and Bob Moskovitz provided GIS support. Luis Acedo assisted in data entry and geological technical support. Barbara Wanish and Dianne Vaughn prepared the final landslide hazard zone maps and the graphic displays for this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Cotton, Shires and Associates – review files for the Town of Saratoga and the City of Cupertino	182
County of Santa Clara	58
Town of Los Gatos	28
County of Santa Cruz	22
Total Number of Shear Tests	290

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Castle Rock Ridge 7.5-Minute Quadrangle, Santa Clara County, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
California Geological Survey
***Formerly with CGS, now with U.S. Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf.

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full

7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's web page:
http://www.conservation.ca.gov/CGS/index.htm.

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

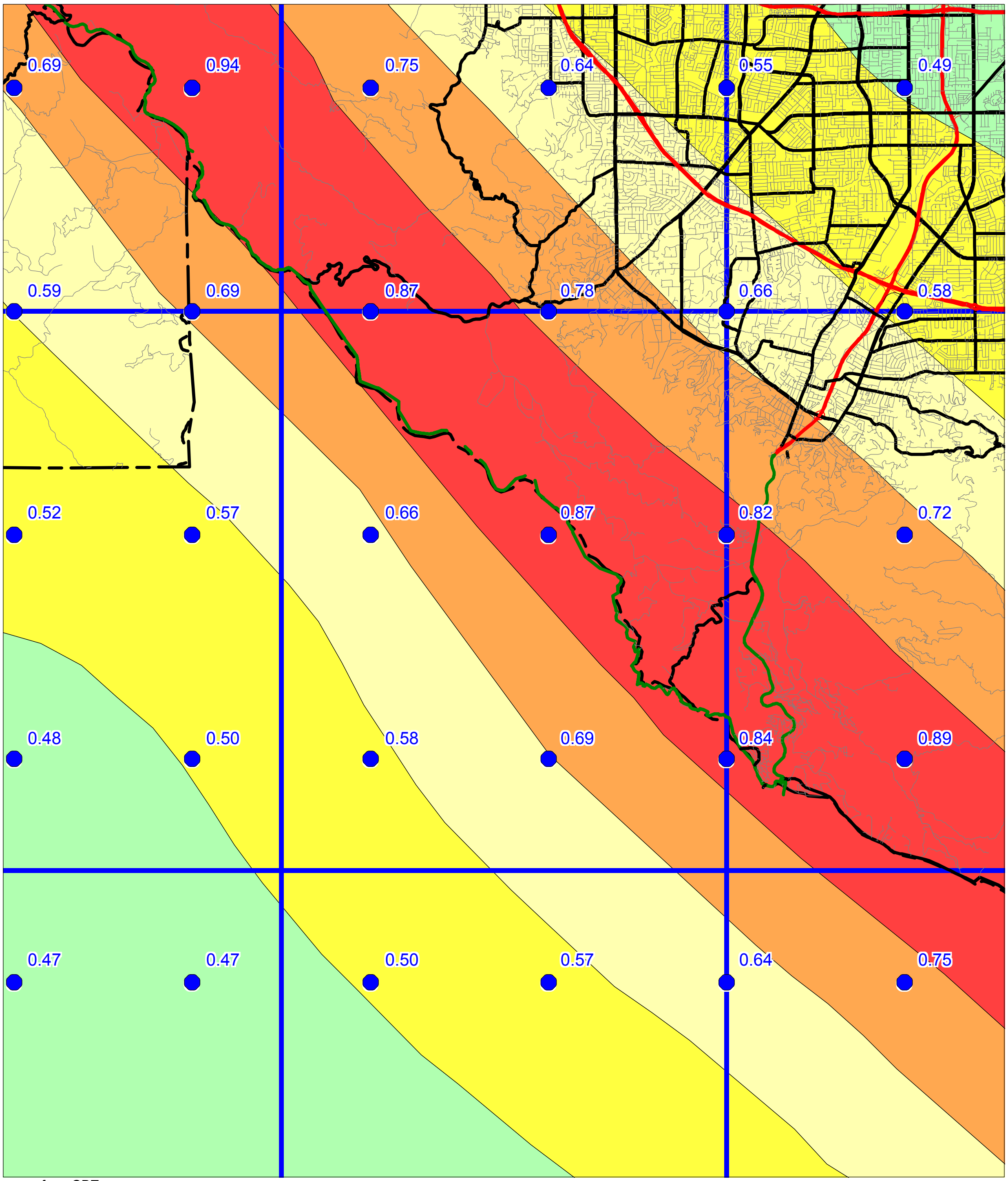
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

CASTLE ROCK RIDGE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map from GDT

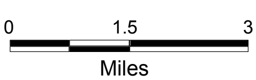


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Figure 3.1

CASTLE ROCK RIDGE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS

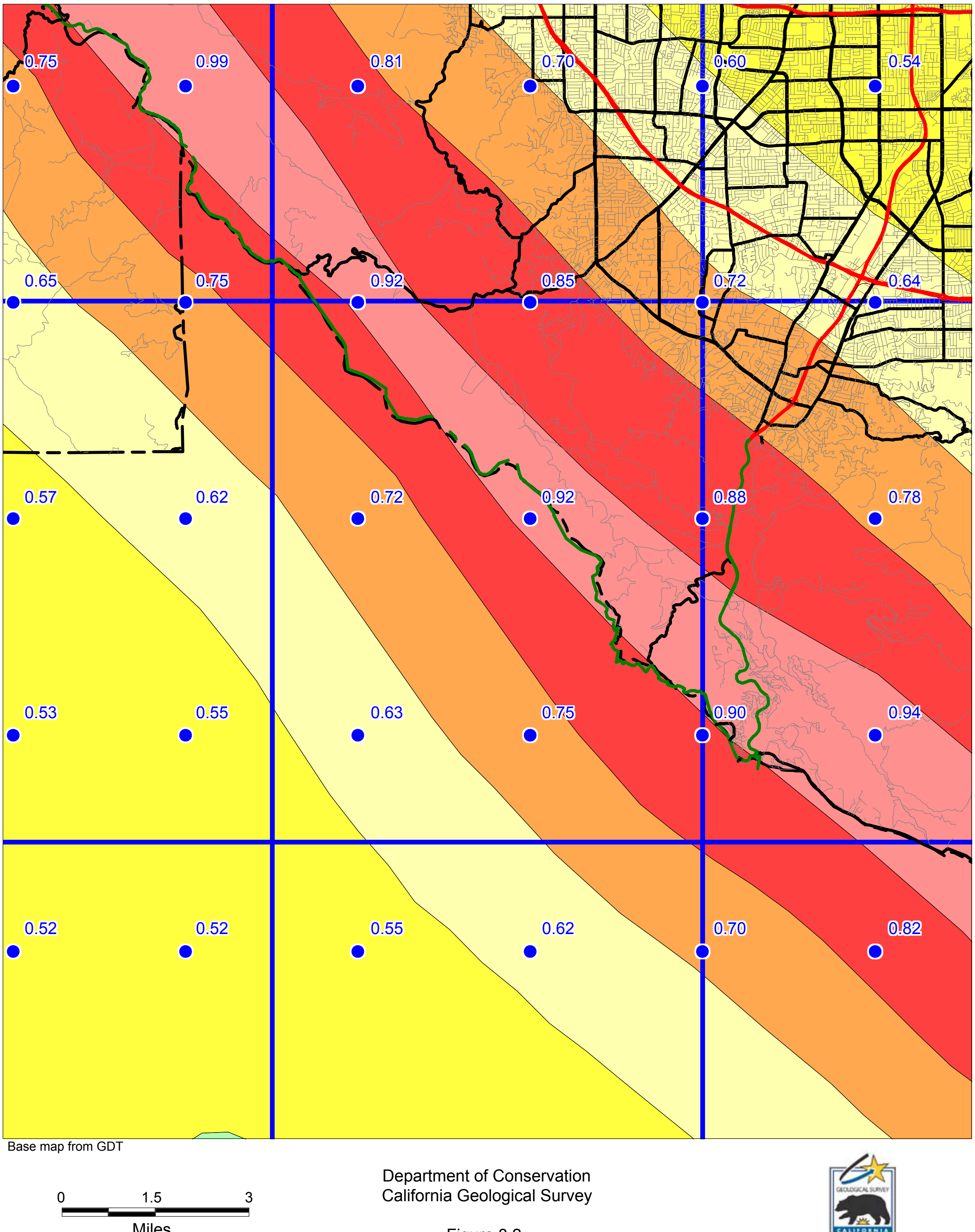

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Figure 3.2

CASTLE ROCK RIDGE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS

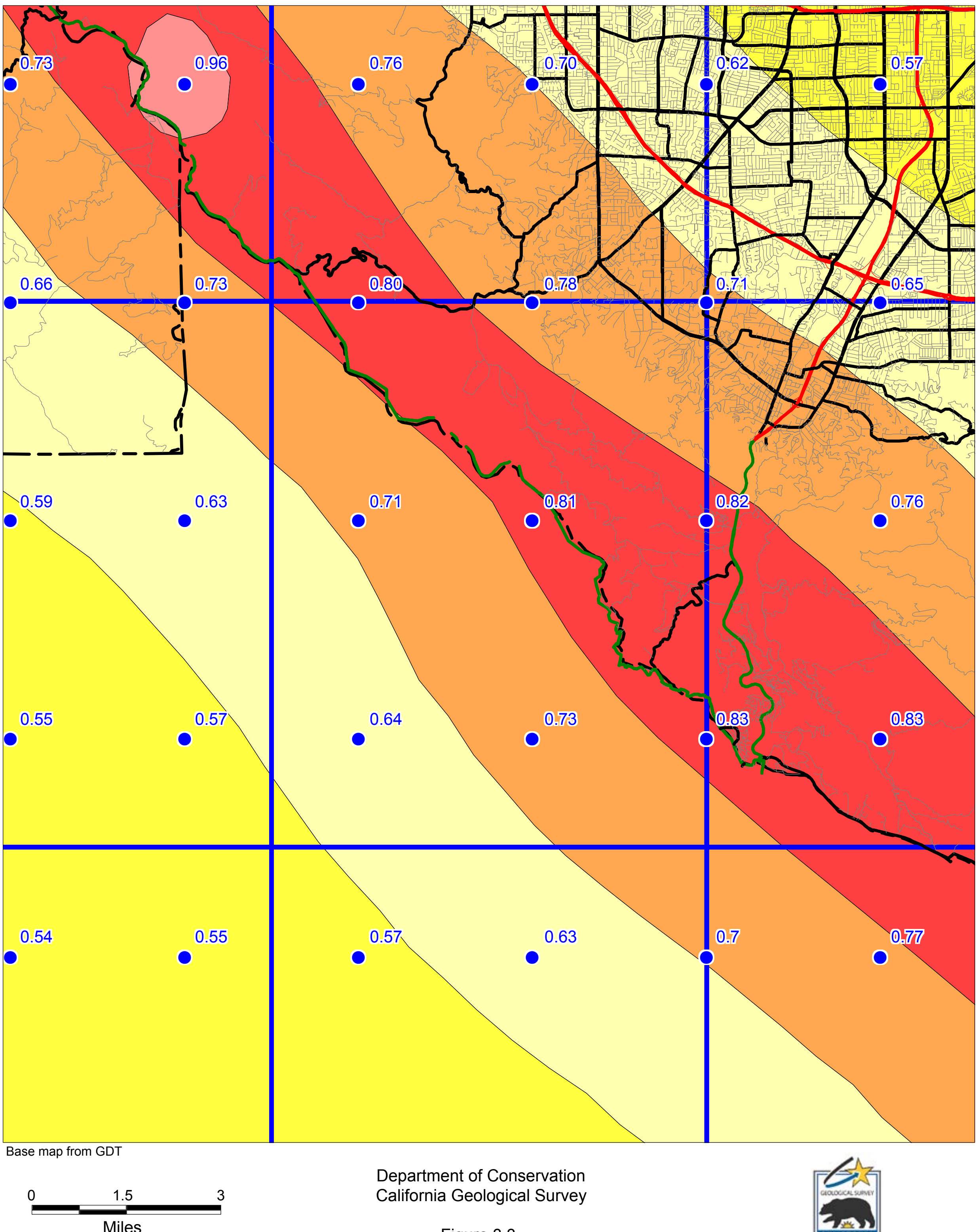

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Figure 3.3

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the "simplified Seed-Idriss method" of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a "magnitude-weighted" ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

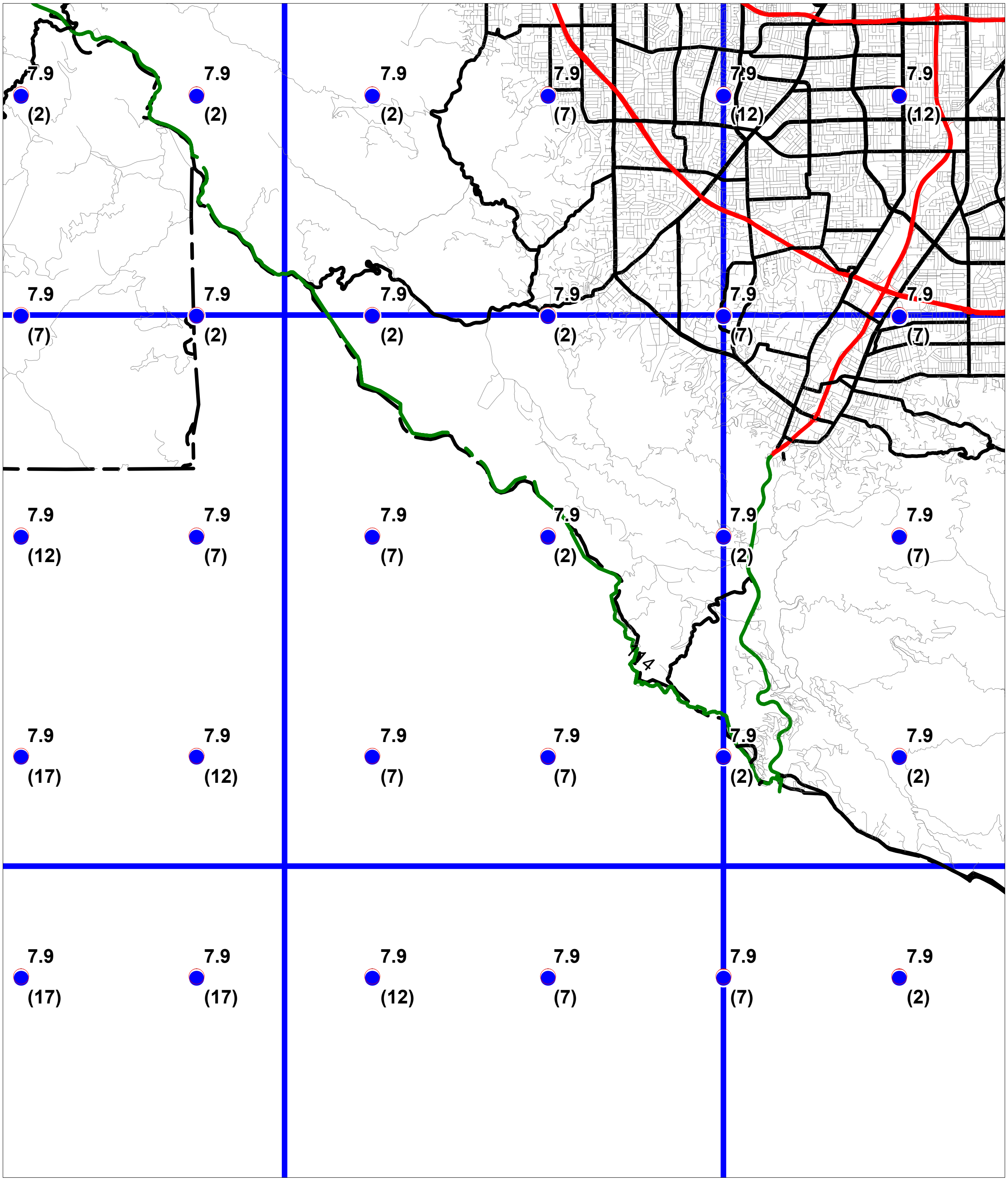
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

CASTLE ROCK RIDGE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

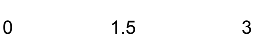
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT



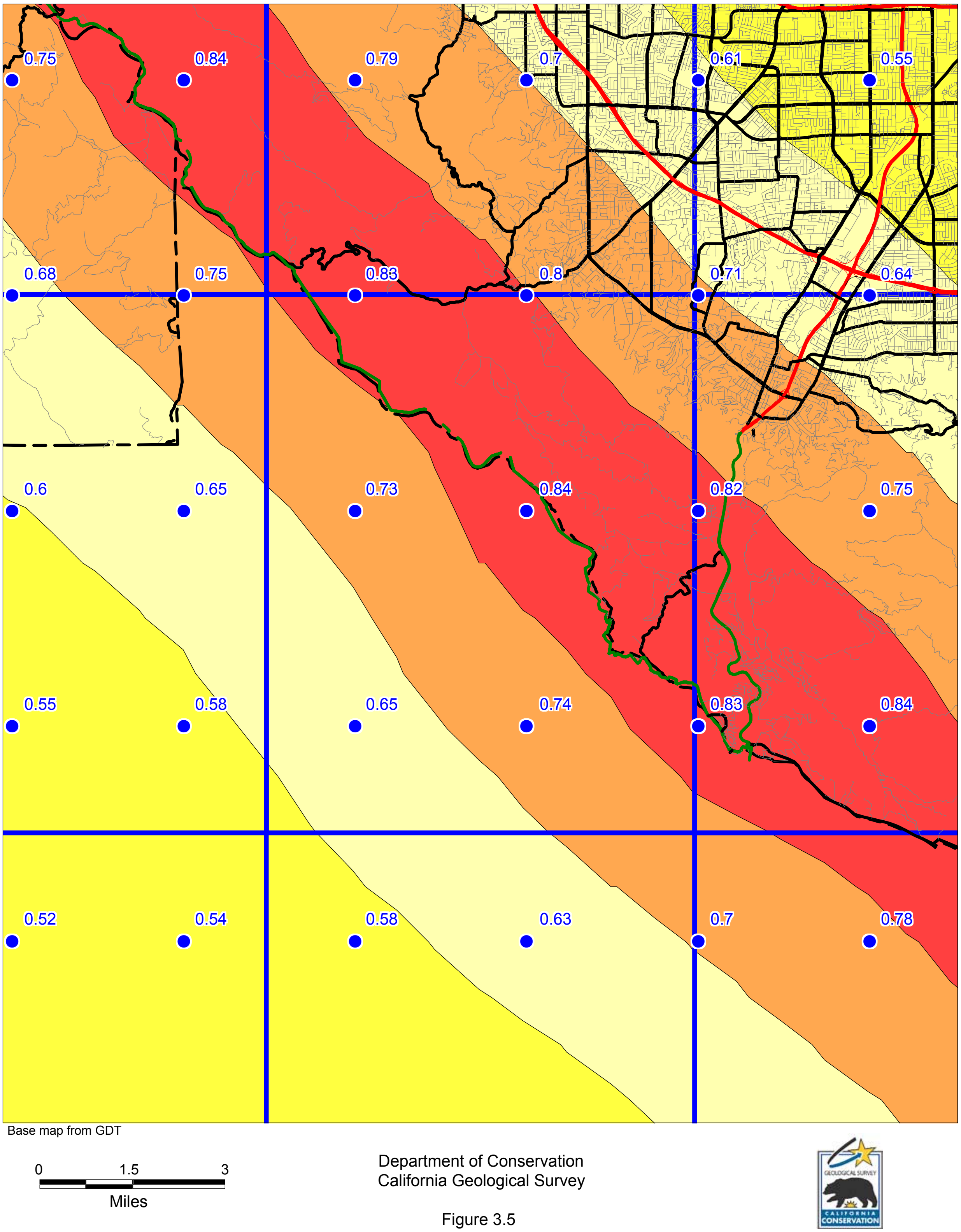
Department of Conservation
California Geological Survey
Figure 3.4

CASTLE ROCK RIDGE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



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California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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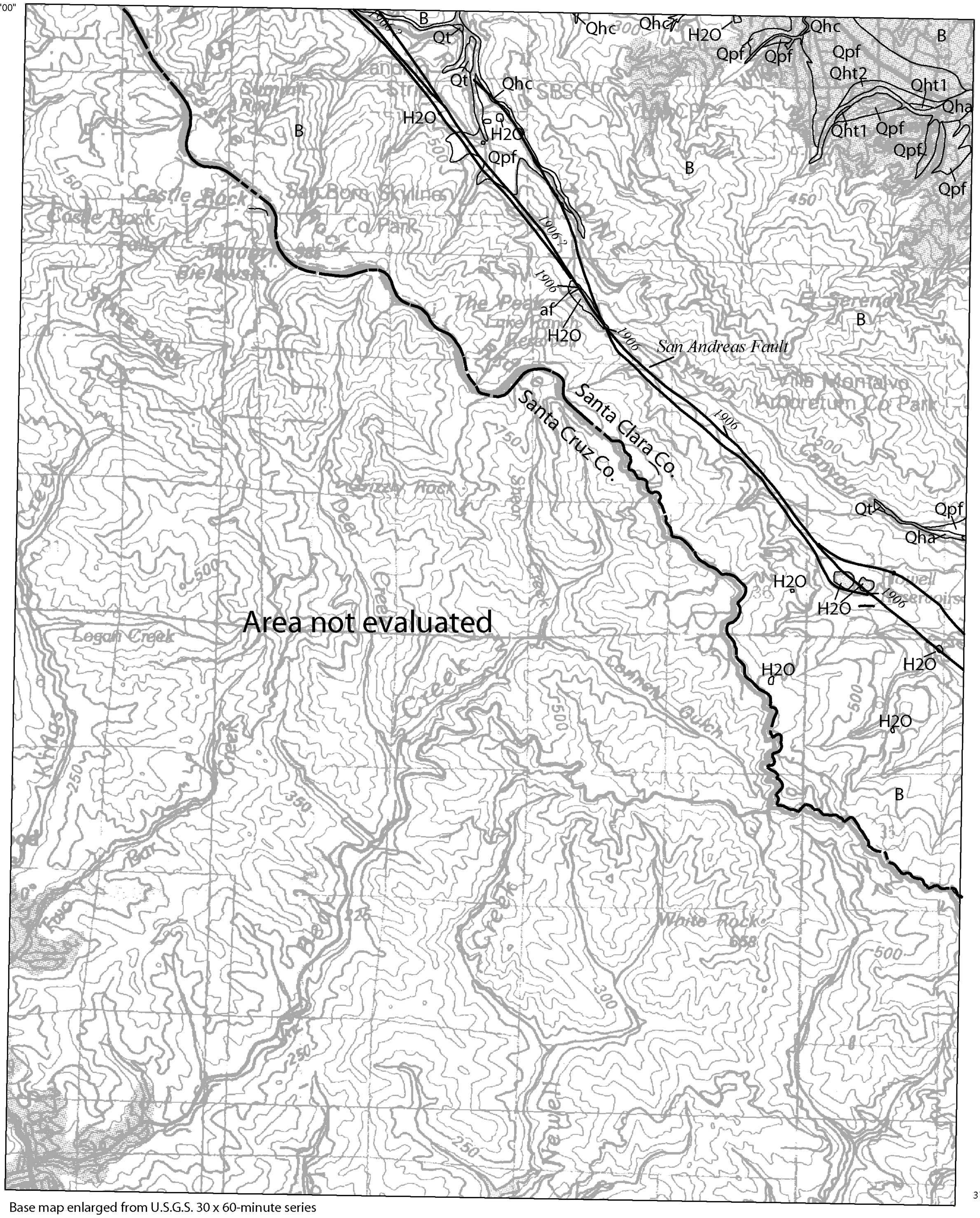
122°7'30"
37°15'00"



37°07'30"

Base map enlarged from U.S.G.S. 30 x 60-minute series

122°0'00"

CASTLE ROCK RIDGE QUADRANGLE

SCALE

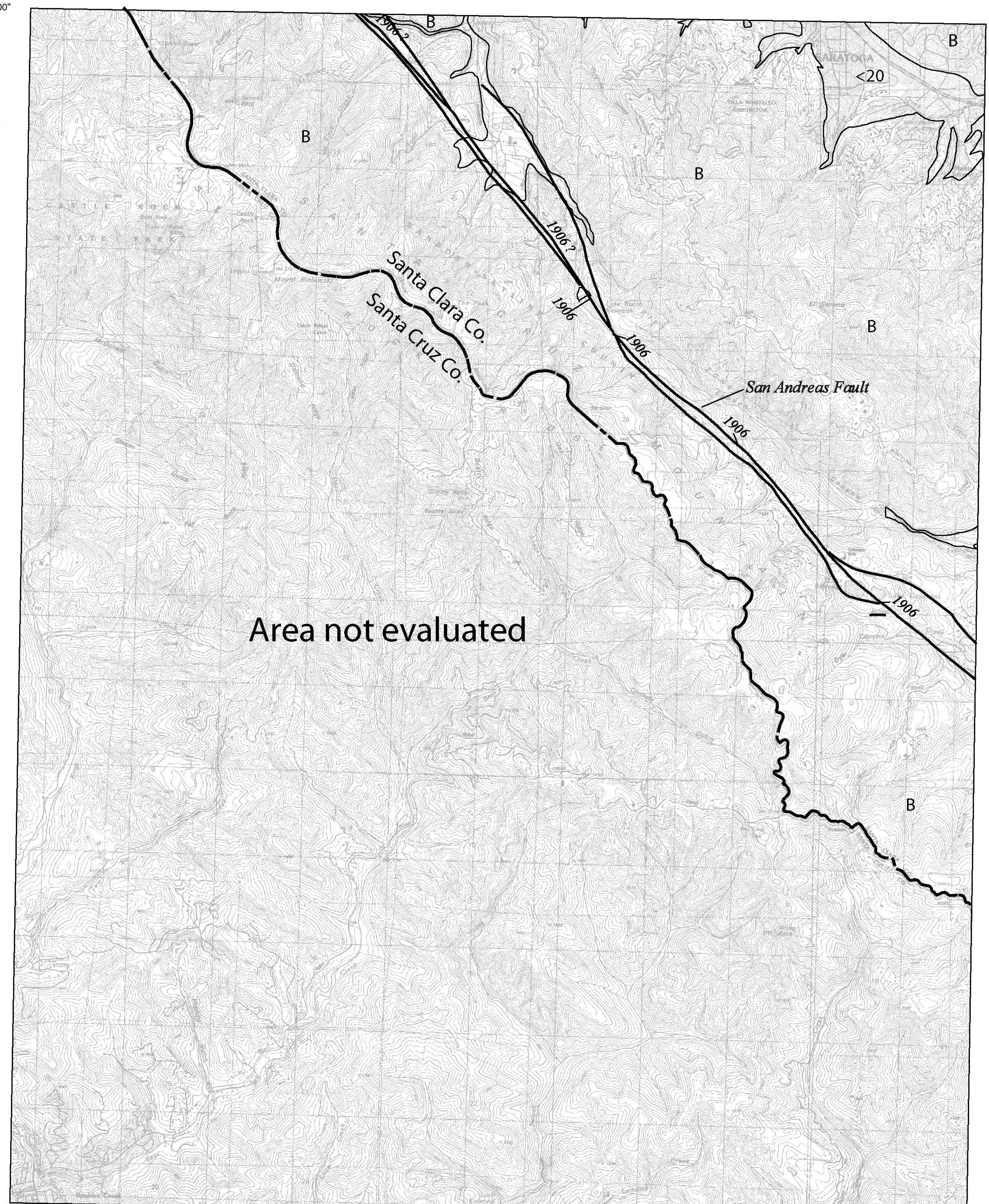
N

San Andreas Fault trace from Bryant and others (2001) showing 1906 ruptures

B Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Castle Rock Ridge 7.5-Minute Quadrangle.



Base map from U.S.G.S. 7.5-minute series

CASTLE ROCK RIDGE QUADRANGLE

SCALE

N

50 ft Depth to ground water

San Andreas Fault trace from Bryant and others (2001) showing 1906 ruptures

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.2 Depth to historically high ground water for Castle Rock Ridge 7.5-minute Quadrangle, California

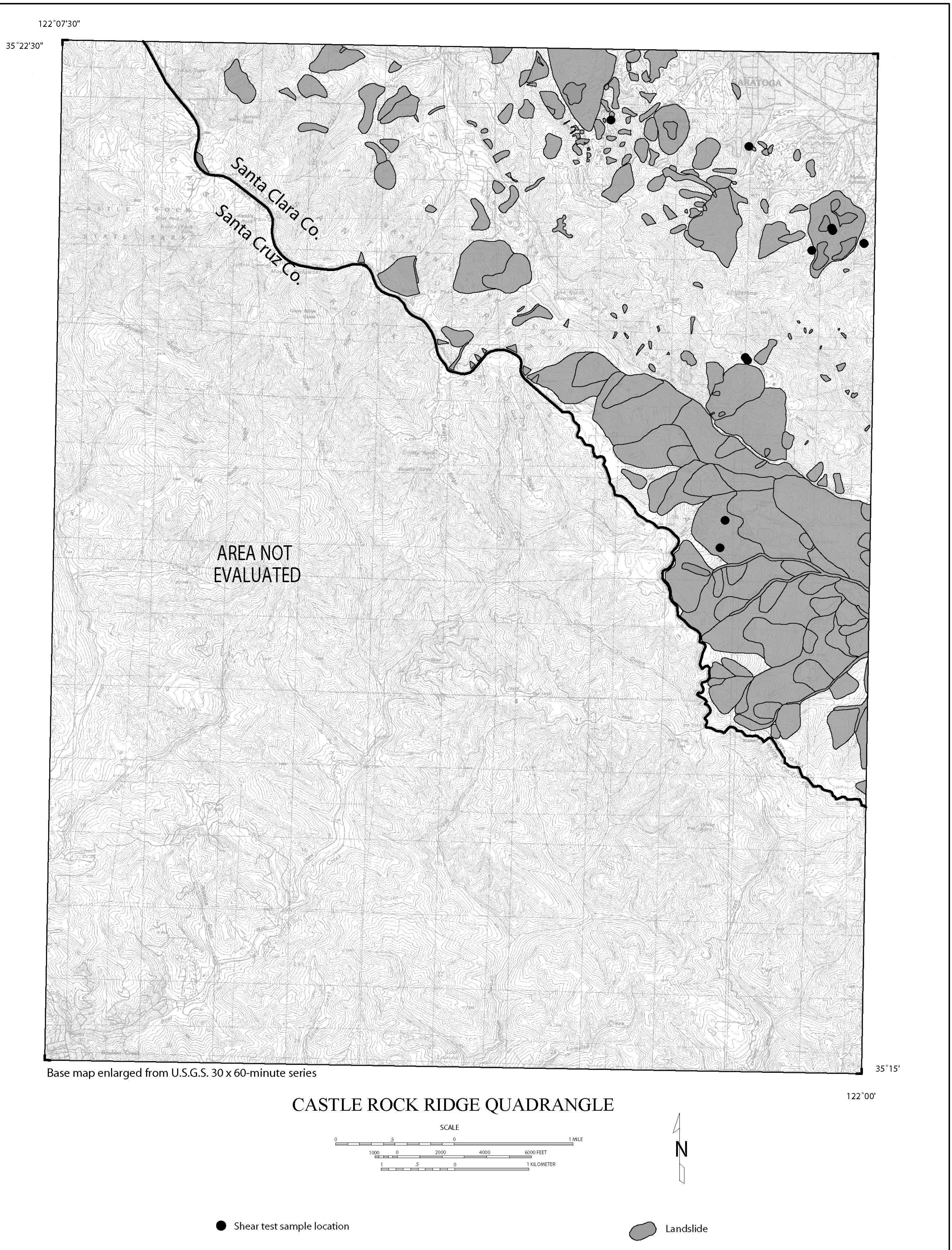


Plate 2.1 Landslide inventory, and shear test sample locations, Castle Rock Ridge 7.5-Minute Quadrangle, California.